

QUANTUM INTERPRETATIONS FOR BUILDING SCIENCE/RELIGION BRIDGES

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ABSTRACT: This paper attempts a systematic comparison of the multiple interpretations of quantum mechanics (QM). The article ends with a summary table that has 13 rows and 10 columns. The columns are metaphysical principles such as determinism and reality. The rows are the main interpretations from 1925 to the present. Each row has entries such as Yes/No/Agnostic. We have contacted most of the living authors and based on their comments we have modified the entry for their interpretation. However, there is reasonable space for disagreement when it comes to determining the correct value of each box (Yes/No/Agnostic). We hope to improve the table in the future. We have also eliminated one of the columns and replaced it with two new columns. We believe that this topic is especially relevant to bridge building in dialogues on science, religion and spirituality because of the unique way that QM brings out metaphysical questions from within science. While any science may lend itself to metaphysical speculation, few sciences beyond QM have such a wide range of metaphysical speculation that all correspond to the same empirical results. This fact may humble scientists and have interesting consequences for how to build bridges between conflicting worldviews.

KEYWORDS: Quantum mechanics; Science and religion; Metaphysics

I INTRODUCTION

We seem to be living in a special cusp in the history of human society when ecological and human condition disasters are possible in the next century if present societies cannot learn to resolve their differences. We think that there are lessons to be learned from quantum mechanics (QM) for how to build bridges between conflicting worldviews. We submit that scientists' lack of humbleness and sometimes-outright hostility toward religion or spirituality is not conducive to this goal. Even some

theologians seem to limit their notion of divinity to what has become known as a “God of the gaps.” A parallel problem exists within the university as well as between science and humanities. Today new kinds of “two cultures” problems exist, including differences in vulnerability to funding cuts as well as new types of ideological differences (for more see David Hollinger [1]).

Our first goal is to explore how the many conflicting interpretations of quantum mechanics can provide guidance for showing how bridges can be built between conflicting points of view. Second, modern science has given us a fundamental theory, QM, explaining what is going on at very small scales. There is general agreement among quantum scientists that “nobody understands quantum mechanics,” as Richard Feynman famously put it [2]. In this quote Feynman was of course speaking of “understanding” in the sense of intuition or “common sense.” The situation wherein QM is not held to make intuitive sense is what motivates QM experts to *interpret* QM. It is very common to find that the proponents for one interpretation of QM find their interpretation to make great sense, and try to convert others to their side. This does lead to debate but does not always lead to a strong understanding of the points of view of others. Methods of theology or philosophy may help build mutual understanding of metaphysical systems.

2 MULTIPLE ONTOLOGIES IN PHYSICS?

Ontology is the philosophy of being and the nature of what exists. Ontology may be contrasted with epistemology, or the philosophy of knowledge and its limits. Upon reflection, it is easy to see that any philosophy of epistemology must contain ontological considerations, and vice versa. The possibility of conceiving that there could be “multiple ontologies” has an equally long history, and is perhaps justifiably located in the traditions of philosophy that consider becoming as prior to being, as in Herodotus. In recent years, the word “ontology” has escaped philosophy and spread across the disciplines, taking on differing technical meanings in fields as different as cultural anthropology and computer science [4,5]. Various authors in physics have referred to the different interpretations of quantum mechanics as different “ontologies” as well [6,7].

For the purpose of our current analysis, we begin with a reference to Wikipedia’s Tabular Comparison of the multiple interpretations of quantum physics (from here on, the “Wikipedia Table” or just “Table”). The Table can be found on Wikipedia’s “Interpretations of Quantum Mechanics” page. The original Table provides 16 rows and 10 columns. The 16 rows are names of different interpretations of leaders in the field of foundations of quantum mechanics. No two rows have identical entries. The 10 columns are different characteristics that can identify differences between possible

interpretations. We consider each of the 16 rows a distinct “ontology” according to the various values presented by the columns. Our Table modifies the original table and removes some of the rows for the sake of clarity. Eventually we intend to add other rows for more recent interpretations that are not included here, such as the “Quantum Bayesian” interpretation.

What makes the multiple ontologies of quantum physics unique is that each *ontological* picture is constrained by very similar if not the same *epistemological* constraints: those of scientific method. To put this more simply, all of the interpretations of quantum mechanics, with the exception of two “objective collapse” theories, make exactly the same experimental predictions. To explore how such very different ontologies can emerge from the same evidence, it is only necessary to point to the “strange” (at least from a classical physics point of view) phenomena quantum physics provides such as entanglement. It follows that each of the 10 columns contains values that, although they are not fully determined by experimental constraints, are at least bounded by such constraints. Below, we describe each of the columns to show how the different “ontologies” (the rows) emerge out of disagreements on how to resolve certain interpretive questions in quantum mechanics (the columns). For example, the “Observer Role” category contains a “Yes” for the Von Neumann column and a “No” for the Many Worlds column. This implies consciousness plays a fundamental role in QM according to Von Neumann. Such a role is not admitted by Many Worlds. However, the “Many Worlds” interpretation leads to a no less surprising picture of the universe, wherein which everything that could happen does happen, leading to the famous branching of huge numbers of universes.

We should note that the present authors are not authors of the Wikipedia Table. The Wikipedia Table as it stands almost certainly contains mistakes (this point is discussed further below). However, we suggest this table as a model for developing a method to understand how very different ontologies can emerge from the same evidence, or what is agreed to be the same evidence. By analyzing similarities and differences between the various ontologies, it becomes possible to make groupings and show how those groupings tend to follow similar ontological commitments. We believe that becoming self-aware of ontological commitments is an important step in making productive dialogue across very different ontological positions such as those that occur in science, religion, and politics.

		Determinism	Wave function Real	Hidden Variables	Collapsing Wave Fun	Observer Role	Localiz	Counter-factuals	Universal Wave	Out. Mind Qualia	New Predictions
Epistemic/Monistic Idealism											
Copenhagen	Bohr, Heisenberg	No	No	No	No	Yes	No	No	No	No	No
Quantum Logic	Birkhoff	No	Agnostic	No	No	No	Agnostic	No	No	No	No
Stochastic	Nelson	No	No	No	No	No	No	No	No	No	No
Consistent Histories	Griffiths	No	No	No	No	No	Yes	No	No	No	No
Relational	Rovelli	No	No	No	Yes	Yes	Yes	No	No	No	No
Ontic-Nondeterministic/Dualistic ontology											
von Neumann	von Neumann	No	Yes	No	Yes	Yes	No	No	Yes	Yes	No
Objective Collapse	GRW	No	Yes	No	Yes	No	No	No	Yes	No	Yes
Objective Collapse	Penrose	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes
Transactional	Cramer	No	Yes	No	Yes	No	No	No	Yes	No	No
Monistic Physicalisms											
1) Ontic-Hidden Variables-Deterministic											
Hidden Variables	Bohm/ deBroglie	Yes	No	Yes	No	No	No	Yes	No	Yes	No
Time Symmetric	de Beauregard	Yes	No	No	No	No	Yes	No	Yes	No	No
2) Ontic-Hyper-Determinism											
Many Worlds	Everett	Yes	Yes	No	No	No	Yes	No	Yes	No	No
Many Minds	Zeh	Yes	Yes	No	No	No	No	Agnostic	Yes	No	No

Table 1. Revised version of Wikipedia’s tabular comparison of interpretations of quantum mechanics.

The table demonstrates how organized similarities and differences can emerge from categorical analysis of quantum interpretations. Of course, these preliminary results are only the very beginning of the development of a comparative approach to interpretation of quantum mechanics. We believe that a comparative approach that explores and takes into account the source of ontological differences between interpretations can be at least as productive as the usual polemical approach to quantum interpretation that chocks up evidence, persuasive argumentation and rhetoric for its own side while trying to poke holes in other camps. It may turn out that the sources of such ontological differences are quite various and interesting in themselves: they may include empirical, rational, aesthetic and perhaps even ethical or political considerations [8,9]. Our intention is to develop improved methods for comparison and encourage others to do the same.

2.2 *Some Definitions of Columns.*

The differences between the columns show how vastly different worldviews can emerge from the same evidence. Here we review some of the columns and consider how the definitions of the columns can give rise to different ontologies.

Determinism. This column asks the question of whether outcomes are probabilistic. Many of the standard interpretations have a probability involved so most of the entries in that column would be “No”. A few exceptions would be if there are hidden variables, such as in the Bohmian interpretation. The Many Worlds/Minds (MW) interpretation is deterministic, but not in the usual sense, since Many Worlds claims that all that exists is the wave function. This leads to the well-known “many worlds,” which we have labeled a “hyper-determinism” to distinguish from the classical meaning of this word.

Wave function real and Universal Wavefunction. This is the clear distinction between Copenhagen and von Neumann. We interpret “real” to mean “ontological,” and likewise, a “No” implies a primarily epistemic interpretation. Note that although Bohmian mechanics is ontological in its interpretation, it is not the wave function itself considered real, but the underlying “implicate order.”

Hidden variables: This is similar to Determinism, as mentioned above. The Bohmian interpretation is the cleanest example.

Collapsing wavefunction: The ontic dualistic interpretations have a collapse, by definition of the dualistic aspect. The collapse signifies a real distinction between two worlds with different descriptions, for example, classical and quantum (as in Objective Collapse) or physical and mental (as in von Neumann). Interpretations in the epistemic category imply that real collapse is avoided. “Collapse” in that case signifies a change in knowledge. Insofar as “Copenhagen” is an umbrella category for many variations of interpretations, we may consider some of the more modern epistemic versions as modernized Copenhagen interpretations.

Observer Role: This category is well known in the Copenhagen and von Neumann interpretations. It implies a human observer playing an “active” role. However, the interpretation of the role of the human observer is different in different cases, because an “active” role for Copenhagen implies an activity in the sense of a limit on possible knowledge (no collapse is explicitly postulated by Bohr or Heisenberg), whereas for von Neumann “collapse” is often associated with the “I” or mind. The philosophical subtleties here can run deep.

Counterfactual Definiteness (CFD) and Locality: These two columns have an important relationship because the standard reading of Bell’s Theorem states that quantum mechanics can admit of a world that has CFD or locality but not both (an interpretation such as Copenhagen that admits neither CFD or Locality is allowed, of course) [7,14]. The standard definition of CFD is “there is a definite outcome to experiments that have not been performed,” and so denial of CFD is a denial of that postulate. Only Bohm says Yes for CFD. For Many Worlds/Minds, CFD is an ill-posed question since all possibilities are actualized.

Predictions different from von Neumann: Only Penrose and Ghirardi–Rimini–Weber (GRW) are in this category since objective collapse requires a dynamical “collapse” hypothesis that would be testable. In fact, an experiment to test the Penrose hypothesis is under construction.

Ontological Mind/Qualia: Some interpretations make claims that go beyond the “physical” into the domain of “mind.” For example, Roger Penrose has famously speculated an identity between his objective collapse mechanism and qualia. Certain versions of von Neumann, such as those proposed by Wigner and Stapp, also make ontological claims about the relationship between mind and QM.

3 DIFFICULTIES WITH THE TABLE

Our general project of clarifying the table leads to certain foundational difficulties of both physical and linguistic natures. In this section, we review some of the difficulties and dilemmas that emerge in our attempt to form a comparative analysis of quantum interpretations.

3.1 *Column definitions.*

The original column definitions varied by row. For example, the meaning of the word “determinism” does apply to Many Worlds, but in a way that significantly changes the commonly understood meaning of the word. Variation of meaning of columns across rows is not as easy a problem to surmount as it may first appear. This is because an attempt to fix the definition of a column to a single meaning tends to favor one interpretation over the others. This is especially true for column names that do not refer to specific problems that have been conducive to mathematical demonstration, but problems can easily emerge anywhere. The “Observer Role” column has a highly philosophical meaning. It is clear that defining an observer as only a human observer has philosophical implications and favours epistemological and consciousness based interpretations over other interpretations. In other words, this column derives from the concerns of those interpretations that emphasize an “Observer.” If an “observer” can be a Geiger counter, as many if not most physicists contend, then the column would be moot. We shall only mention in passing the question of whether a mouse or an amoeba can be an observer for “consciousness-based” interpretations.

The column called “counterfactual definiteness” maybe understood to refer to the aspect of Bell’s inequality that states that any hidden variables theory can admit either realism or locality but not both. Counterfactual definiteness is a rigorous definition of “reality”; it implies that there is a fact of the matter about events that have not occurred [7]. However, some physicists have challenged the assumption that Bell’s

theorem presumes counterfactual definiteness and therefore the theorem pertains only to locality. One might hope that for situations like this one that are more rigorously definable, a common solution might be attainable through rational argumentation. (We hope to come up with a definition and word for rows in which this ambiguity appears.) It remains to be seen whether this is the case.

3.2 *Difference of Emphasis and Terminology.*

A plunge into the literature on foundations of quantum mechanics reveals a plethora of very technical arguments and problematics. For this reason, we have consulted with experts for advice and corroboration. Nonetheless, the experts do not agree either. In our initial consulting of the experts on quantum foundations, we have found strong variance in emphasis not only in answers, but also in what is considered to be the main or most important problem(s). (We do not here reveal the names of our sources since information was gathered for ethnographic purposes, in a context that assumed privacy.) Some initial results are as follows: For a leading proponent of objective collapse theories, the central problem is that fact that quantum mechanics does not account and cannot account for “the line between what is classical and what is quantum” [or] “what is reversible and what is irreversible.” An expert on Many Worlds, in contrast, explained that the quantum wave function should be taken at face value, and argued that Many Worlds, though strange, is the world-picture that emerges from doing so. Such a position would seem to do away with the need for a classical-quantum boundary. That is, there need not be a collapse or “cut.” However, similar to the Bohm interpretation, our universe is “riding the wave” like a surfer. Meanwhile, a proponent of Copenhagen has argued that the “classical-quantum boundary” is impossible to do away with, since the parameters of the quantum formalism remain defined by “classical” concepts that derive from our everyday experience.

3.3 *Fundamental Language.*

This brings us to the last consideration of our review of difficulties in producing a meaningful comparison of quantum interpretations: what we will call “fundamental language.” Most physicists are not familiar with linguistics, but nevertheless quantum interpretation brings up questions not only about the nature of the physical universe, but also the relationship between words and things. The fact that pre-collapse quantum physics does not seem to describe “things” at all makes the problem even more complicated. Some physicists consider Niels Bohr’s deliberations on language arcane, and we will not review them here, but at least one of us (Cochran) believes that a more widespread knowledge about the nature of language, including more modern theories of language, would be of help to developing a better comprehension of exactly what is

disagreed upon when physicists disagree on quantum interpretations.

We will mention briefly, as an example, that Jim Hartle's [10] "Quantum Physics and Human Language" is a valuable step in this direction. Yet it suffers from a kind of "spontaneous philosophy" of language, as if knowledge of what language is and does can result from mere introspection. It is impossible to review here the wide variety of research programs on language. We will mention just one concept from linguistic anthropology, that of "language ideology," which refers to what a given culture believes language to be, and how these beliefs form the culture's way of using their language [11]. It turns out that "language ideology" varies greatly from society to society, and even between sub-groups within societies. We bet, given anthropological evidence, that what physicists think about the nature of language has an effect on how they interpret quantum physics. We think Hartle's paper corroborates this view, yet perhaps even more so than he knows. In his fieldwork, Cochran noticed that physicists often assume their peers understand what they mean, and miscommunication often goes unnoticed for fear of appearing less intelligent or out of touch, c.f. Susan Traweek's [12] ethnography of physicists. The tendency to demand that language has an objective referent leads to a masking and unawareness of subjective valences of language that are never entirely absent.

4 DISCUSSION

Our discussion has two parts that attempt to connect our work on quantum interpretations to our social goal (like dealing with climate change) that was brought up in the Introduction. The first part is straightforward. We have argued that other than the Objective Collapse interpretations all interpretations give identical predictions for all possible experiments. Yet as we have discussed the various interpretations are quite different from each other. This is our powerful argument for humility between factions with conflicting worldviews. Quantum mechanics provides an example that maybe there are ways for people to accept each other's strongly held religious views. Keep in mind that typically religious views cannot be discriminated with scientific experiments.

The second aspect of our discussion involves an aspect of the quantum mechanics that enables further tolerance between different religions. To clarify that aspect requires us to go into more detail about the mechanisms of the quantum calculations. The basic framework of quantum mechanics evolved between 1925-1927 with Bohr, Born, Schrodinger, Heisenberg and Pauli. Von Neumann's *Mathematical Foundations of Quantum Mechanics* [13] became the bible for the mathematical underpinnings of the new theory. We find it convenient to refer all Interpretations to how they differ from the Von Neumann Interpretation. We break von Neumann into three steps. Step 1 is

the evolution of the wave function amplitude or what Feynman called the sum over paths. For simplicity let us consider the double slit experiment. The outcome of Step 1 is an amplitude distribution on the detector. The amplitude is a complex number that has a magnitude and a phase, as is natural for a wave. Step 2 is the observation that replaces the complex wave function by a probability that is the square of the amplitude and the phase information is lost. For experiments that are more complicated than the double slit experiment it is often easier to discuss the situation in terms of a density matrix where the diagonal of the density matrix is the probability distribution and for Step 1 the off-diagonal elements have the phase information. In Step 2 (the measurement) the off-diagonal elements become zero. Step 3 is when an observer looks and the probabilities are converted to actualities. It is often common to combine Steps 2 and 3, since “for all practical purposes” they are the same, but our colleague Henry Stapp has for many years eloquently pointed out the importance of separating these steps [14].

We would like to emphasize that in the standard interpretation of QM going from Step 2 to 3 is called the Born rule whereby the actuality (Step 3) is given by a random outcome of the probabilities. It turns out the empirical tests of the Born rule are much less stringent than the empirical tests of Step 1, such as QED calculations of the magnetic moment of the electron accurate to 12 decimal places (the diameter of a human hair relative to the distance to the moon) and the energy levels of Hydrogen with almost the same accuracy. Proponents of Divine Action have pointed out that the test of the Born rule is much less accurate. We point this out because in this discussion we want to connect the various interpretations to our overall goals we discussed in the Introduction. We pointed out that an important aspect of our motivation for engaging in this project was to build bridges between different worldviews that will be needed to solve world problems like global warming. We need science and religion to have healthier relationships. We suggest building bridges by speculating whether God’s divine action could be implemented via Born Rule violations given the rough tests of the Born rule accuracy [15].

In the Introduction we pointed out that an important aspect of our motivation for engaging in this project was to build bridges between different worldviews that will be needed to solve world problems like global warming. Not surprisingly, the American Association for the Advancement of Science (publishers of Science magazine) has recently been devoting substantial resources in helping religions become more science literate. Two years ago AAAS has funded 10 US seminaries to introduce science into their curricula. One of those seminaries is the Jesuit School of Theology at Berkeley, and one of the co-authors (Klein) together with Bob Russell are the science advisers.

Russell is the founder and director of the Berkeley Center for Theology and Natural Sciences (CTNS). We mention this because over a recent 20 year period CTNS and The Vatican have organized conferences resulting in a six volume set of books all with the subheading “Scientific Perspectives on Divine Action”. Two volumes are specifically on quantum mechanics, the others are on Chaos/Complexity, Evolution/Molecular Biology, and Neuroscience. The sixth volume is an overview of the entire project. Summaries of all 91 chapters can be found at <http://ctns.org/books.html>. We believe that our present project on the interpretations of quantum mechanics will be a useful resource for future projects seeking to find common ground between the sciences and the religions.

5 CONCLUSION

Developing a comparative framework from which to discuss QM interpretations is a fruitful direction to explore how meaningful connections and dialogs can be made across divides between science and religion. Only very small headway is made in that direction in this paper. It is clear that developing literacy across the two domains is necessary for such a project. In the current case, this was made possible by Klein’s long-time efforts in Science-Religion dialogues, and the fact that Cochran is an ethnographer of religious and spiritual views of scientists. In closing, we remark that from a more general point of view, the recognition that constructive rather than merely critical projects that combine science and theological methods can be productive for all, but considerable effort and dedication of time is needed.

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